

## Whole Range Calibration: Version 5.WR

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NOTE: Aquarius Version 5.WR is a research product based on Version 5.0 and designed to improve the accuracy of brightness temperatures at the warm end for applications over land and ice. To access this data, contact the PO.DAAC at: <https://podaac.jpl.nasa.gov>.

### A. Introduction

The goal of Aquarius is to measure sea surface salinity in the open ocean, and the calibration of the instrument has been tuned to achieve this goal. There are two calibration scenes which are sufficiently large and uniform, and sufficiently well known to be appropriate for this purpose, cold sky and the ocean itself. Both have been used in the calibration of Aquarius, but after the initial removal of a bias, the calibration uses only the ocean itself. In particular, after the initial post-launch check for bias, the cold sky was used only to look for temporal changes (i.e. to check stability).

In the ideal case, the Aquarius calibration would use two points (e.g. cold sky and ocean) and be checked at a third (land). Or, even better, the calibration would use cold sky and a non-ocean scene such as land or ice and then be verified over the ocean. Unfortunately, this is not practical because scenes at the warm end (e.g. 250 K which is typical of land and ice at L-band) are generally not known with sufficient accuracy over large enough area (on the order of 100 km) to be compatible with the Aquarius footprint.

Because the brightness temperature of the open ocean at L-band has a very limited dynamic range, it is possible to have a calibration which is accurate and reliable for application over the ocean but not as accurate at the warm and cold extremes (Figure 1). However, Aquarius collects data continuously including global coverage of the land and ice and there are potential applications of these non-ocean measurements (e.g. soil moisture over land) which could make good scientific use of this data.

The objective of the “Full Range” calibration is to extend the calibration of Aquarius so that the Aquarius brightness temperatures can also be used reliably for applications at the warm end. This has been done by including the cold sky in a two point (cold sky and ocean) calibration. Essentially, this amounts to drawing a straight line between these two references and extending it to warm brightness temperatures (Fig 1).

Version 5.WR is an extension of V5.0 in which a secondary calibration that uses the cold sky is performed. This is superimposed on the V5.0 data. That is, the procedure begins with V5.0 and adds an additional step in which the cold sky and ocean observations (V5.0) are used to tune the calibration. The change is a linear transformation from the old, V5.0, antenna temperatures to

the new, V5.WR antenna temperatures:  $TA\_V5.WR = a TA\_V5.0 + b$ . The changes have minimal effect on the data over ocean (Figure 2) or the retrieved salinity (Figure 3) because the ocean global average  $Ta$  is kept unchanged by design.

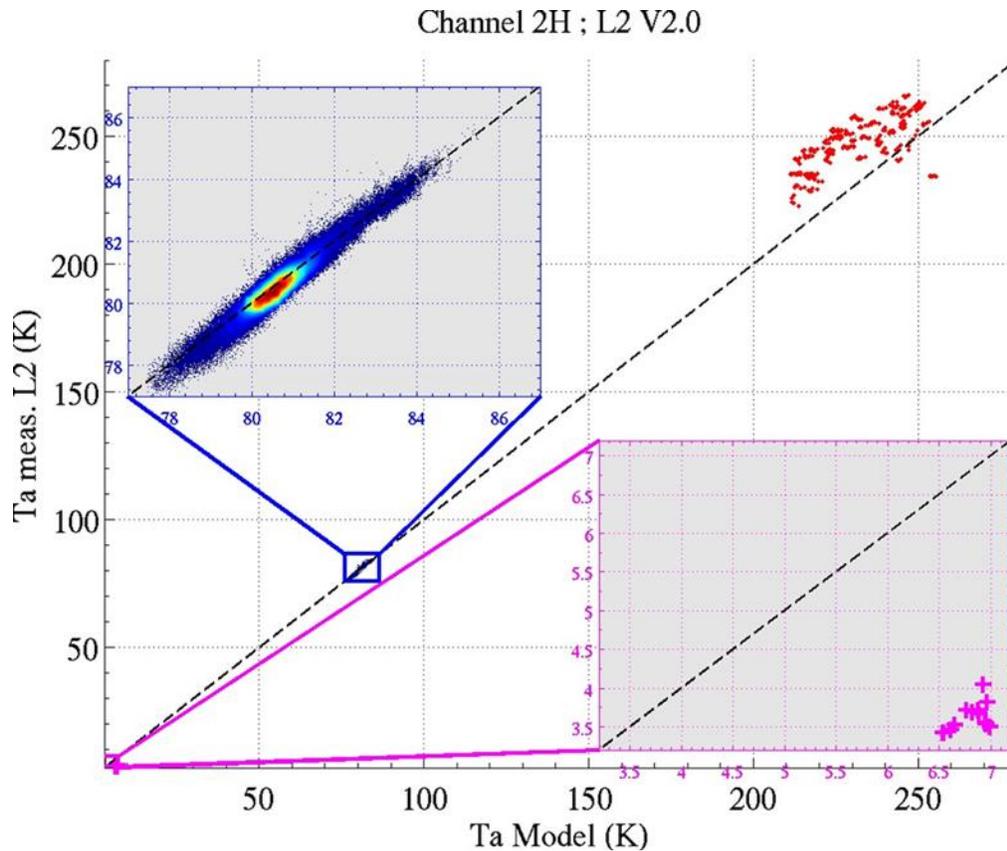


Figure 1: Plot of Aquarius antenna temperature,  $Ta\_measured$  against the antenna temperature predicted with the forward model,  $Ta\_model$  for three regimes: Cold Sky (pink insert), Ocean (blue insert) and land (Little River Watershed, red dots). The data is for horizontal polarization and the middle beam and the measurements are from V2.0 of the algorithm. Although the fit to the ocean is very good, the measurements at the cold end are cold and at the warm end, too warm. By adjusting the slope slightly and keeping the  $Ta$  fixed over the ocean, one achieves a better calibration over the whole range of the measurements. This is the objective of the whole range calibration.

There was much discussion regarding whether or not (V5.WR should become the final official Aquarius product. However, because the calibration in V5.0 was focused on the optimum SSS product, a decision was made to keep the two products separate and to offer the whole range calibration as a separate research product (V5.WR). To avoid confusion, especially to those not well versed in the subtleties of the differences, it was decided that access to V5.WR be available to the public but only after special request to the PO.DAAC.

## B. Whole Range Calibration

The objective of the Whole Range Calibration (WRC) is to adjust the radiometer calibration so that the radiometric observations match simulations of antenna temperatures (“expected” TA) over the whole range of TA encounter by Aquarius for natural targets (i.e. cold sky, ocean and land/ice). To do this, observations over the celestial sky ( $\sim 5 - 10$  K) are used in addition to those over the ocean ( $\sim 100$ K) to determine a linear correction for the radiometer. The large difference in antenna temperature helps determine the slope as a function of the target TA in a way not possible with only ocean observations which have a small dynamic range.

The WRC does not impact significantly the SSS retrievals because the recalibration includes the observations over the ocean as already calibrated. The slope as a function of TA does change but the effect on the ocean is minimal because the dynamic range of TA over the ocean is small. The impact of the WRC will be seen mostly for observation of the celestial sky (for which biases exist in V5.0) and TA over land and ice. The objective of the WRC is not to improve the SSS retrieval but to improve the retrieved TB of the surface at the warm and cold ends to allow for science applications other than SSS and for inter-comparisons with over L-band instruments (e.g. SMAP and SMOS) over the sky and land/ice.

The adjustment to TA is a linear transformation according to the expression:

$$T_{A,new} = a \cdot T_{A,old} + b$$

with  $T_{A,new}$  the updated Aquarius observation using the WRC and  $T_{A,old}$  the Aquarius TA before WRC as found in V5.0. The procedure is illustrated in Figure 1. The coefficient  $a$  corrects gain inaccuracies and  $b$  corrects for a constant bias. The line defined by these coefficients is the new calibration curve that relates the observations in V5.0 ( $T_{A,old}$ ) to the new TA. The coefficients are derived from a linear regression between two points:

- At the cold end, with  $T_{A,old}$  the mean of the TA measured by Aquarius for the 30 cold sky calibrations and  $T_{A,new}$  the mean of the simulated TA (i.e. “expected TA) for the cold sky calibration.
- Over the ocean, with  $T_{A,old}$  the mean of the TA measured by Aquarius globally for the year 2012 (using the data filtered for RFI, and with a water fraction of  $\geq 99.9\%$ ) and  $T_{A,new}$  the mean of the corresponding simulations (“TA expected”).

Table 1 reports the results for the computation of the coefficients  $a$  and  $b$ :

Table 1: Values for the coefficients  $a$  and  $b$  .

	V-pol		H-pol	
	$a$	$b$	$a$	$b$
Beam 1	1.003350568406014	-3.592857280825468	1.007405352181248	-6.595668007611077
Beam 2	1.008337848581688	-9.655610862597533	1.003498234086013	-2.948722716952730
Beam 3	1.017695610594212	-2.233911609523380	1.001311195384693	-1.075651639210478

C. Effect on TA over the Ocean

The effect of the whole range calibration has very small effect on the antenna temperatures and salinity retrieved in V5.0. This is illustrated in Figures 2 and 3 which show (Fig 2) the difference between the expected and retrieved antenna temperature ( $T_f - T_{exp}$ ) for V5.0 and V5.ER, and the difference between retrieved salinity and in situ measurements (Fig 3) in the case of V5 and V5.WR. That is, the two figures show the difference in antenna temperature over the ocean and retrieved salinity with (V5.1) and without (V5.0) the extra full range calibration.

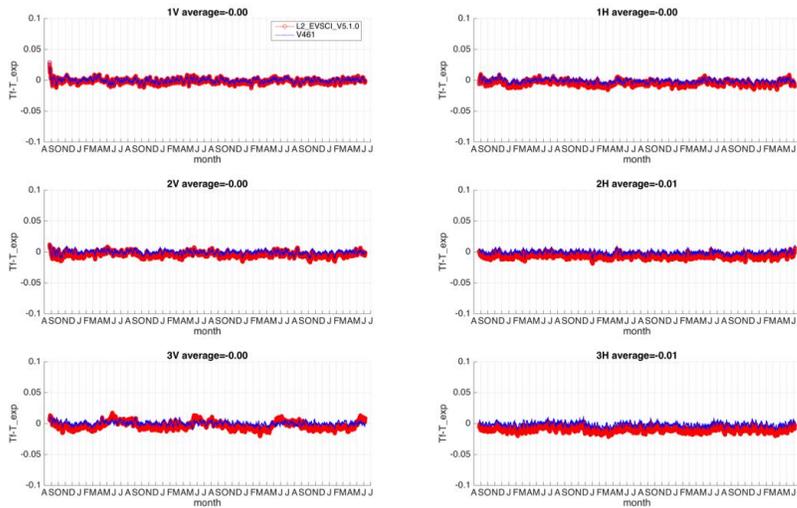


Figure 2: Difference in antenna temperature between observation and simulations over the ocean with (red) the full range calibration (V5.WR) and (blue) without (V5). Differences are for weekly global average  $T_a$ .

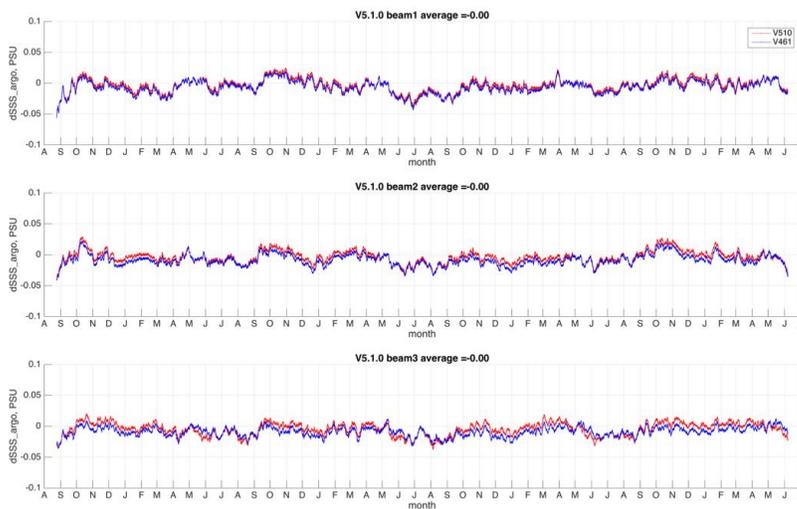


Figure 3: Difference between retrieved salinity and in situ measurements using (red) the full range calibration (V5.WSR) and (blue) without (V5.0).

D. Improvement of TA over Land and Cold Sky

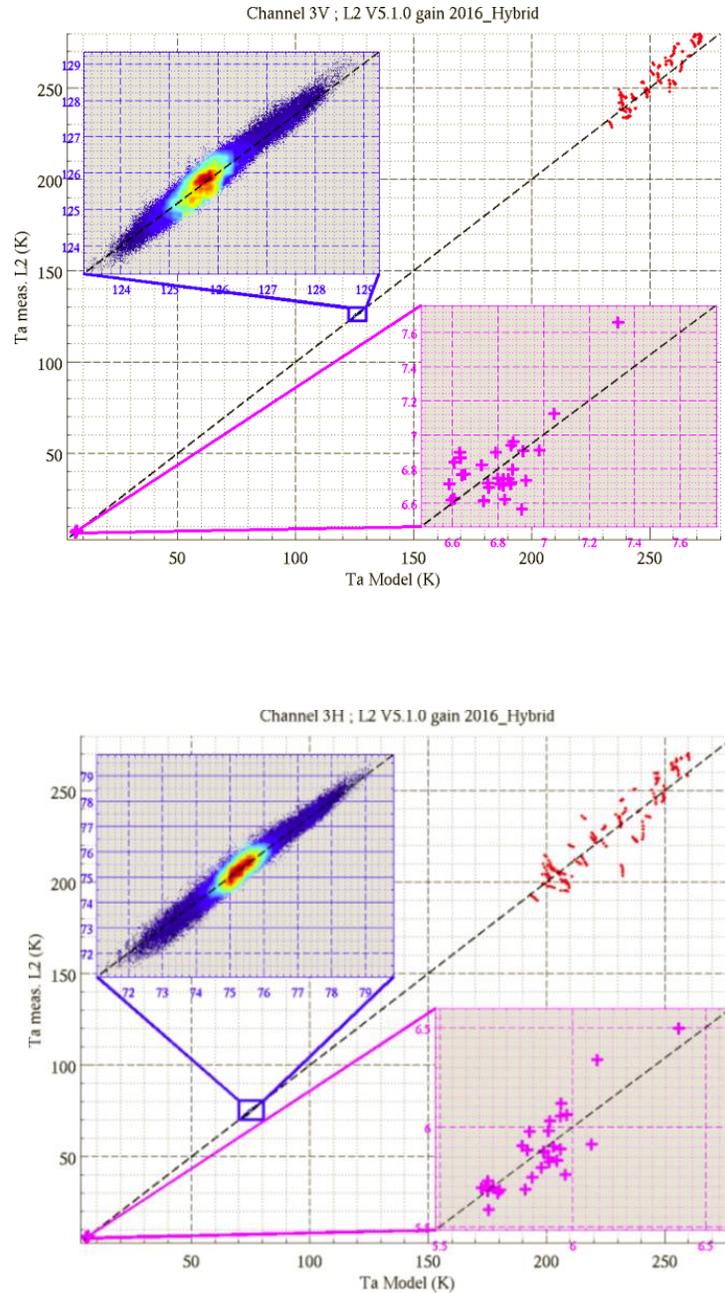


Figure 4:  $T_a$  measured by Aquarius versus simulated over (magenta inset) the Celestial Sky, (blue inset) ocean and (red dots) land, for the outer beam at (top) vertical and (bottom) horizontal polarizations. Insets are close-ups of ocean and Sky data. The Aquarius data are from V5.1, the final release with full range calibration.

Figure 4 shows a comparison of the V5.0 data with the full range calibration with expected results for land and cold sky. The data at the warm end are from measurements over the USDA Little Washita watershed which is instrumented for monitoring soil moisture. Because of the large footprint and fixed orbit of Aquarius was not possible to use the same scene for all beams. The improvement compared to earlier versions of the algorithm and without the whole range calibration is evident when compared with the example in Figure 1. The improvement at the cold end is significant. The change over land is as much as 2.2 K (V-pol and outer beam) and generally on the order of 1K. These changes are small compared to the uncertainty in the model due to uncertainties such as in the surface truth (soil moisture), effect of vegetation and the small size of the scene compared to the footprint of the radiometer, and work to further validate the results at the warm end is underway.

Additional references:

E. P. Dinnat, D. M. Le Vine, R. Bindlish, J. R. Piepmeier and S. T. Brown, "Aquarius whole range calibration: Celestial Sky, ocean, and land targets," 2014 13th Specialist Meeting on Microwave Radiometry and Remote Sensing of the Environment (MicroRad), Pasadena, CA, 2014, pp. 192-196. doi: 10.1109/MicroRad.2014.6878937

E.P. Dinnat, D.M. Le Vine and L. Hong, "Aquarius Final Release Product and Full Range Calibration of L-Band Radiometers", IEEE International Geoscience and Remote Sensing Symposium (IGARSS), July, 2018.